Northwest Aggregates Maury Island Gravel Mine
SEPA Review of Additional Information

Prepared for:

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1 INTRODUCTION

This document is intended to assist King County in their determination as to whether a Supplemental Environmental Impact Statement (SEIS) is needed for a proposed new dock at the Maury Island Glacier Northwest Gravel Mine site. The decision on whether or not a SEIS is needed depends on whether the new dock would cause a probable significant adverse impact under SEPA or whether new information submitted by opponents of the project in response to the dock application would have a bearing on that decision. King County asked Jones & Stokes to review the proposed new dock concept, as described in Huckell/Weinman, 2003, and to review other new information submitted since issuance of the Final EIS (FEIS) on the project in June 2000, to determine if any of this information would trigger the need for a SEIS under SEPA. This document does not evaluate shoreline management and land use issues associated with the dock application. King County is evaluating those issues.

1.1 Background

King County issued a Final SEPA EIS on the proposed dock facility and sand and gravel mine in June 2000. The proposal was to mine up to 7.5 million tons of sand and gravel annually from a 235-acre site on Maury Island in King County, Washington. The proposal was to use the existing dock facility, which would receive minor repair at the outset of the project and occasional piling replacement over the next 5-15 years.

One of the recommendations in the FEIS was to replace and extend the existing dock. This would move tug operations further from the shoreline and from two eelgrass beds identified in the EIS and would avoid continued repairs. There were technical, operational and permitting issues associated with this recommendation that took considerable time to investigate and/or resolve. The applicant, Glacier Northwest, submitted an application for a new dock and operations plan for the facility in September 2002. Opponents to the proposal, and the new dock, submitted comments and studies in response to the new dock application that dispute assumptions made in the supporting studies related to the new dock application, and that dispute other findings related to the project. King County asked Jones & Stokes to evaluate the significance of all of this new information to determine whether a Supplemental EIS under SEPA is needed. This determination would be made after it was determined whether or not significant adverse impacts are now evident which were not evident or previously addressed when the FEIS was published. The review was to follow the supplemental EIS guidelines under SEPA.

1.2 Scope

The scope of this effort includes review the proposed new dock design, the proposed new draft mitigation plan, and new information submitted to King County from the public, to determine whether a supplemental EIS is needed. King County staff members are evaluating land use issues separately. The King County Responsible Official under SEPA will make the final decision after reviewing the two analyses. If it is determined that a supplemental EIS is not needed, the County is likely to issue an Addendum under SEPA to address the new information. Our approach toward the review of this information under SEPA significance criteria is discussed below.

1.3 Supplemental EIS or Addendum – Requirements under SEPA

This discussion of SEPA and how it might be applied to this project was prepared as guidance to all reviewers at Jones & Stokes, and as a guide to all readers, so that they might review all of the information submitted in the same context. This review considers the relevance of information submitted since issuance of the Final EIS in June 2000.

1.3.1 SEIS Requirements under SEPA

There are two guidelines under SEPA that define the need for a Supplemental EIS. An important factor in the applicability of these criteria is the definition of significance. The SEIS criteria is discussed below. The significant criteria are discussed in Appendix A.

SEPA states (WAC 197-11-600(3)(b)) that "…preparation of a new Threshold Determination or supplemental EIS is required if there are:

(i) Substantial changes to a proposal so that the proposal is *likely** to have significant adverse environmental impacts; or

(ii) "New information indicating a proposal's *probable** significant adverse environmental impacts. (This includes discovery of misrepresentation or lack of material disclosure.)"

**Emphasis added*

A SEIS is not required, however, if those impacts are covered within the range of alternatives and impacts analyzed in the original FEIS. This interpretation comes from WAC 197-11-620, which states: "The SEIS should not include analysis of actions, alternatives or impacts that is (sic) in the previously prepared EIS".

We read both of the criteria above to support issuance of a SEIS if <u>new</u> and likely significant adverse impacts not discussed in a Final EIS are now evident, either through project changes or new information. In the first criteria (i) a SEIS may be required if the proposal changes and new significant adverse impacts are created by the change and are likely. In the second case (ii) we conclude this to mean that new information that indicates that there are probable significant adverse environmental impacts not discussed in the previous EIS may be cause for a supplemental EIS.

Note that in both definitions, the new significant adverse impact must be "probable" or "likely". A possible new impact does not meet the threshold for requirement of a SEIS.

The term "significant", and its many and complex definitions under SEPA can include many small impacts and other factors besides an obvious adverse impact. For this reason, and to support the County in its Threshold Determination on this project, we have included a discussion of each of the significance criteria within SEPA and how each might be applied to the differences between the project and impacts described in June 2000 vs. the project and impacts described in 2003. Among the factors influencing the conclusion of significance under SEPA are location; a combination of "marginal" impacts; unique and unknown risks to the environment; effects on public safety; and other factors as described.

1.3.2 Addendum under SEPA

An Addendum[1], on the other hand, is a document with wide discretion of use under SEPA. It is generally issued when analysis or information about a proposal is added that does not substantially change the analysis of significant impacts and alternatives in the existing environmental document (WAC 197-11-600(4)(c)). Under SEPA, an Addendum may be issued by a Lead Agency if additional information arises that the agency feels the public should be aware of regarding a proposal. An Addendum can be issued after release of a Draft EIS or a Final EIS, but is generally issued after a Final EIS. An Addendum provides new information, but does not analyze impacts or evaluate issues of environmental significance under SEPA. There are no requirements for public comment to an Addendum. It is to be sent to anyone who received a copy of the original EIS.

The SEPA definition of an Addendum under WAC 197-11-706 is "…an environmental document used to provide additional information or analysis that does not substantially change the analysis on significant impacts and alternatives in the existing environmental document". An addendum is not appropriate if new information uncovers a new and probable significant adverse environmental impact; or if it indicates a likely increased significant adverse impact above that discussed in earlier documents.

We have not analyzed the pros and cons of an Addendum, or whether it would be appropriate to issue one. This analysis is solely based on the SEIS criteria. If an SEIS is determined by King County to be required, no Addendum will be prepared. If no SEIS is issued, the County will decide whether or not to issue an Addendum. The decision analysis here is based on the Threshold Decision for an SEIS under 600(3)(b)i and ii.

1.3.3 Similarities and Differences Between SEIS and Addendum

There are common elements to either decision—Addendum or SEIS. Scoping is not required for either. The document would be very limited in scope. Distribution of either document is required. King County would not hold a public meeting for an Addendum but is likely to hold one for a supplemental EIS. The SEIS would solicit public comment. The Addendum would normally not solicit comment. King County, however, has informed the residents of Maury and Vashon Island that they would be provided a 30-day comment period on any Addendum for this project, should one be issued.

If a SEIS is prepared, other procedures such as distribution, public meetings, receipt of comments during a 30-day review period, and a draft and final document are followed, just as with a Draft EIS.

[1] This analysis does not evaluate the criteria for an Addendum. The decision will be whether the criteria for an SEIS are or are not met. We do not consider whether the contents of a potential Addendum, for example, would meet Addendum criteria. This analysis is based solely on SEIS criteria.

1.4 Determination of Significance

As Lead Agency under the Washington Sate Environmental Policy Act (SEPA), King County must determine whether new information made available since issuance of the FEIS in June 2000 would identify new significant adverse environmental impacts. This analysis will determine whether a SEIS is required or whether it is appropriate to issue an Addendum and/or proceed with the permitting decision. This discussion focuses on the threshold determination process or need for one, and definition of significance under SEPA. This information was used by all authors at Jones & Stokes to determine whether or not the new dock design and the information submitted by the public would trigger significance criteria and support a Determination of Significance and the need for a Supplemental EIS. Under WAC 197-11-600(3)(b) "a new threshold determination is not required if probable significant adverse environmental impacts are covered by the range of alternatives and impacts analyzed in the existing environmental documents".

Although this document reports the determination on the need for a SEIS, rather than the need for an EIS, the significance criteria listed in SEPA are the same in either case. A synopsis of SEPA significance threshold criteria is given in Appendix A.

2 PROJECT DESCRIPTION

This Threshold Determination is based in part on the new project (extended and re-designed dock) submitted by the applicant for mitigation. This section describes the new dock based on the *Maury Island Revised Dock Proposal Report* prepared by Huckell/Weinman in March 2003. We did not review the actual dock design submittal.Various terminology used in the industry for project elements may be confusing so they are defined here;

Pier – Same as dock

Dock – The offshore berthing structure lying approximately parallel to shore against which barges would berth while being loaded,

Dolphin – A set of pilings fastened together in the vicinity of the dock to be used as bumpers for barges to lie against.

Trestle – A combined structure connecting the shore facilities to the dock and comprised, in this project, of three elements; the conveyor, the gallery and the trestle foundation

Trestle Foundation – A steel supporting structure held up over water by three piling sets called "bents" which is attached to and supports the gallery

Gallery – A 12' diameter steel tube lying on top of the support structure over the bents which contains the 54" wide loading conveyor and a walkway.

Conveyor – A mechanical transport device made up of a belt and side trays moving over rolling wheels extending from 100 feet inland where it is loaded with gravel to a point beyond the dock.

Bent – A set of pilings combined to act as a single piling to be used as a foundation.

.Facility Dimensions

The proposed dock is more open to light transmittance than the original dock plan. The trestle was extended to respond to a mitigation suggestion in the FEIS that the facility be extended to reduce potential impacts to eelgrass. This section summarizes the basic characteristics of the dock that might have a bearing on significance. The FEIS recommended dock replacement and extension as a mitigation measure.

Table 1 compares the proposed facility vs. the facility as evaluated in the FEIS. Although the entire facility is referred to as a dock, this causes some confusion when the berthing structure is also a dock parallel to shore at the end of the tracks and conveyor. For this reason, we refer to the combination of structures as the offshore landing facility in Table 1.

Although greater in length, the new facility would is smaller in overall surface area (from 8,490 ft 2 to 7,340 ft. 2 (Huckle Weinman 2003). This number includes ancillary platform and walkways not included in Table 1. In addition, the dock surface is approximately 75% open grated steel. This increases the light transmittance to the water.

The new dock averages 71.5' further offshore than the original. The north end of the dock would extend 81 feet further seaward and the south end, 62 feet further seaward.

2.1 Materials Handling and Loading

With a proposed new dock facility, the applicant included changes in the sand and gravel handling and loading facilities. The new materials handing system is an enclosed steel tube (gallery) encompassing the 54-inch wide steel conveyor. The tube is 12' in diameter. The conveyor system would run from 100 feet inland to less than 400 feet offshore. Onshore facilities needed for the new design include a 15x20' transfer platform, 20' high.

Barge loading is modified as well. The conveyor would include a telescoping spout to help direct the material and reduce dust as it falls to the barge. The barges will be hooked up to a cable and pulley system, attached to the mooring dolphins, which will move the barge back and forth to help level the load without having to use the tugs as much to move the barge.

Table 1. Comparison of Barge Loading Facility in FEIS vs. Currently Proposed Project [2]

EVALUATION FACTOR/ CHARACTERISTIC	ORIGINAL CHARACTERISTICS FROM JUNE 2000 FEIS	NEW FACILITY CHARACTERISTICS Huckle Weinman (March, 2003)	DIFFERENCES
Trestle Length offshore	175-200' offshore	310' offshore (approximately)	Increased trestle length and gallery of 110' (approximately)
Total Trestle Length	265' (Symonds, 2000)	500'	Includes increase on shore
Trestle Impervious Surface	100% solid deck 175' x 14' (est) or 2,450 square feet (approx)	400' of 12' diameter gallery (4800 square feet); 310' over water or 3,720 square feet	Increase of 1,270 square feet impervious surface
Dock impervious surface	20' (est) by 200' or 4,000 square feet impervious	10' (est) by 500' or 5,000 square feet but 1,250 impervious	Decrease of 2,750 impervious surface (approximately)
Number of Pilings including trestle, dock and dolphins	228; some to be replaced	36-56 pilings after total replacement	One time removal/replacement vs. replacement of 25% of old pilings every few years.
Piling materials	Wood w/creosote	Concrete or steel	No treated pilings
Dock Distance offshore (from 0' MLLW)	115-130'' (Figure 2; revised mit. Plan; 5/5/03)	200 offshore at center (approximately)	North end of dock 81' further out, south end 62' further out; 71.5 feet further out at trestle
Piling replacement need	15% now; remaining over 15 years; 30 pilings in the pier and 30-40 in mooring dolphins	36-56 pilings will be installed for new trestle , and dolphins	One time construction impact with new dock
Piling replacement construction	Air hammer pile driving	Vibrating pile removal Vibrating hammer installation – if possible	Reduced acoustic impact to marine life.
Depth at end of dock	-18' to –40' MLLW; mostly>22'	-40' to –60' MLLW mostly > 50'	Dock depth 10-30' deeper
Number of dolphins	10	7	Also many fewer pilings per dolphin
Depth at outboard of berthed barge	20' to 40'	55' to 70'	
Conveyor system	Open tray	Enclosed tube	Will eliminate conveyor spillage and wind blown sand into Puget Sound

* Square footages are for entire structure, not just for structure over water.

[2] Loading facility is comprised of a "trestle" connecting the offshore dock to shore made up of three supports and a walkway; the dock lying parallel to shore against which the barges tie, and a 12' diameter tube or "gallery" containing the conveyor and also supported by the supports.

2.2 Other Support Elements

The new facility includes seven new steel dolphins to moor the barges spaced 85 feet apart. It would have new lighting above the dock, at the conveyor, and along the dolphin access walkway. The lights would be shielded from residential areas. Five new power poles would be installed near the old structures and some of the existing wood poles would be retained. Steel pile installation may involve vibratory hammering to minimize noise and shockwave effects on fish. Conventional impact hammer techniques are still an option. All in-water work would occur within the construction window of July 31 through February 15th. The actual in-water construction period is 6 weeks.

2.3 Demolition and Removal

Existing facilities would be removed, including 228 creosote treated piles. Existing conveyors and the existing transfer platform would be removed by land. The balance of the facilities would be cut up and pulled and hauled off by barge. Creosote pilings will be pulled out using a vibrating pile hammer or cut off below the bottom if they broke off.

2.4 Environmental Response

Various capture and prevention methods are incorporated into the construction procedures to avoid spillage and falling materials that might otherwise enter the water. Eelgrass beds will be marked and avoided during construction.

2.5 Environmental Impact Discussion

The dock extension was done in response to the EIS suggestion that it be considered to reduce impacts. Moving the dock further offshore reduces impacts to eelgrass because it moves tug operations further away from eelgrass. It reduces shading impacts, removes creosote pilings from the Sound, reduces the likelihood of a materials spill from the barge, reduces tug operations during loading, and moves the operations into deeper and generally less sensitive waters than the shallower operations. Fewer pilings would be installed with the new dock facilities design (36 to 56 piles), compared to total replacement of all old piles (228) over 12-25 years, reducing construction noise from pile driving. Vibratory hammering may be used, but pile driving has not been ruled out. Pile driving may affect fish, although this would occur during an approved (WDFW, Corps, NOAA Fisheries, USFWS) construction window. No new adverse impacts are identified as a result of dock replacement.

3 ISSUES

New information evaluated in this report includes materials relevant to the issues of propeller wash modeling, impacts to water quality (turbidity), eelgrass, and noise. These include a new barge-loading dock design and reports and memoranda from several authors. Table 2 provides a summary of the documents reviewed. Documents reviewed are listed in the bibliography.

Table 2. Issues Summary

Issue	New Information Summary	Sections
New dock design	Dock designed to avoid nearshore impacts identified in FEIS	Section 2.
Propeller wash	Propeller wash was modeled using two different methods, resulting in conflicting predictions. Independent reviewer concludes that neither model provides a clear prediction of velocity with enough certainty to predict the effect of prop wash on eelgrass with certainty	Section 3.1
Water Quality	New barge-loading dock design reduces the potential for fugitive dust and conveyor spillage, avoiding one potential source of turbidity. Propeller wash was identified in FEIS as potential turbidity source. Prop wash modeling does not provide new certainty of this potential impact.	Sections 3.1, 3.2
Eelgrass	New barge-loading dock design avoids potential shade impact identified in FEIS, and reduces prop wash impact potential by moving tugboat operations farther from eelgrass beds. Propeller wash was identified in FEIS as potentially damaging to eelgrass and potential impacts from the new proposal, although still uncertain, are reduced. Mitigation is proposed by applicant in the event that impacts are detected.	Sections 3.1, 3.3
Noise	No new data to indicate a change in noise levels. KC noise limits still apply, therefore there is no new noise impact from the project.	Section 3.4

3.1 Propeller Wash Model

3.1.1 New information

The FEIS identifies potential impacts to eelgrass and other marine organisms from prop wash through three mechanisms, (1) scouring, (2) suspended sediment, and (3) shading caused by air bubbles and increased turbidity. Scouring is caused by elevated bottom currents, which suspend sediments when a certain velocity is reached. The amount of suspension depends on particle size and bottom velocity. The FEIS reviewed the scientific literature with respect to eelgrass tolerance to elevated currents and identified eelgrass capable of surviving, in suitable substrate, where tidal velocities are a high as 2 m/s (Phillips 1984). However, optimal growth was noted under conditions with currents of 0.3 to 0.4 m/s. Additionally, studies conducted by Hart Crowser (1997) assessing the impacts from prop wash from Washington State Ferries concluded that currents with a velocity above 0.75 m/s damaged eelgrass by eroding away overlying sediment and that currents above 1.1 m/s caused extensive damage to eelgrass rhizomes. Based upon the configuration of the dock as originally proposed, the FEIS concluded that considerable damage to eelgrass beds may occur if prop wash was oriented directly at the beds. Modeling of prop wash was not undertaken in the FEIS because of the considerable complexity and uncertainty in relating model results to actual characteristics at the project site and variability in the equipment proposed for use.

The FEIS concluded that any suspended sediment caused by prop wash would be unlikely to result in the burial of eelgrass. Eelgrass is tolerant of some sedimentation and in fact one ecological function of eelgrass is to capture and stabilize sediments. The FEIS also concluded that any increases in turbidity due to prop wash from approaching and departing tugs alone would not lead to a substantial reduction in light sufficient to harm eelgrass. However, if tugs were used to position barges during loading, the FEIS suggested that one patch of eelgrass may be adversely affected due to shading from bubbles and suspended sediments.

In addition to eelgrass, the FEIS evaluated potential effects from prop wash on the sunken barges located at the site, potential damage to eggs of herring, surf smelt, sand lance, lingcod, and rockfish, and any potential effects to salmon or other fish, including their larval stages. The FEIS concluded that the habitat provided by the sunken barges may be damaged by prop wash during tug operations. Similarly, herring eggs were identified as at risk for damage if the prop wash were sufficient to result in damage to eelgrass (and herring eggs were attached to the eelgrass). The FEIS concluded that other eggs, larvae, juvenile and adult fish were unlikely to be harmed by prop wash.

The FEIS recommended specific mitigation measures to avoid impacts to the marine environment from prop wash. These recommendations included: 1) dock replacement and extension to avoid impacts to eelgrass; 2) creation of an eelgrass mitigation area to offset uncertainty regarding potential effects to eelgrass; 3) compensation for habitat that may be impacted by the proposed project by replacing, enhancing, or providing substitute resources or environments per WAC 197-11-768; 4) establishment of an approach and departure protocol for arriving and departing tug and barges; and, 5) establishment of a "haul back system" to positions barges during loading.

Since the issuance of the FEIS the applicant has proposed the following modifications to their original application to address concerns about potential impacts to eelgrass from prop wash: 1) replacement and extension of the dock by an average of 70 feet so that the eelgrass patches are 100 ft from the new dock face; 2) use of a haul back system for positioning of barges during loading; 3) implementation of an approach and departure protocol for tug operations; 4) implementation of a propeller wash monitoring program; and 5) implementation of an eelgrass monitoring program. Details of these modifications can be found in the Draft Mitigation Plan (Northwest Aggregates, May 5, 2003) and Barge Approach and Departure Protocol (Glacier Northwest, August 14, 2003).

Since the issuance of the FEIS numerous additional studies and reviews have been completed attempting to describe likely effects to eelgrass and the marine environment from prop wash associated with arrival and departure of tugs with barges. These include:

1. A Technical Memorandum (September 5, 2002) by Pacific International Engineering (PIE) describing the propeller wash modeling analysis used as the basis for the dock extension;

2. A Report (2 December 2002) by Dr. David Jay presenting an alternative propeller wash modeling analysis and a critique of the modeling effort by Pacific International Engineering,

3. A Draft Mitigation Plan (May 5, 2003) by Northwest Aggregates proposing dock operations to mitigate potential impacts,

4. A Report (June 19, 2003) by Dr. David Hill peer reviewing both the Pacific International Engineering and Dr. Jay modeling reports,

5. A Technical Memorandum (August 14, 2003) by Coast & Harbor Engineering (previously Pacific International Engineering) describing field measurements to calibrate their modeling analysis and critiquing Dr. Jay's modeling analysis,

6. A Protocol (August 14, 2003) by Glacier Northwest describing a tug operations plan and presenting a propeller wash monitoring plan,

7. A Report (22 September 2003) by Dr. David Jay critiquing the Coast & Harbor Engineering Technical Memorandum and the Glacier Northwest Protocol.

The purpose of this document is to assist the County in determining if a supplemental EIS or and addendum to the FEIS is appropriate, given the new information submitted since the issuance of the FEIS. The criteria for this determination have been detailed in Section 1.3, 1.4, and Appendix A. Of the new information submitted, the applicants modifications to and analyses of the proposal needs to be considered as well as the specific assertions of additional impacts to eelgrass made in the Jay report (2002;2003).

Since the issuance of the FEIS, the applicant has made modifications to their original proposal that are designed to avoid and minimize potential impacts identified in the FEIS. The applicant completed numerous prop wash analyses (JETWASH; PIE September 5, 2002 and Coast & Harbor Engineering, August 14, 2003) and concluded that velocities at the eelgrass areas would be less than 0.75 m/s when tug propellers are located more that 115 feet from the eelgrass.

The Jay report (December 2, 2002) concluded that prop wash could result in maximum near bed velocities that exceed, and in some cases greatly exceed, the threshold for erosion of eelgrass and that elevated velocities capable of impacting eelgrass may occur at distances of 80 to >100 meters (262 to 328 feet) from the tug. Based on these elevated velocities, the Jay report suggests that the eelgrass beds at the site would be damaged and that potentially the larger continuous eelgrass beds north and south of the project area may be impacted as well. These conclusions contradict the statements made by the applicant.

Additional reports have been submitted by both the applicant and the project opposition, each asserting that their conclusions regarding impacts (or lack of impacts) by prop wash to eelgrass are correct. In order to evaluate the issue of prop wash modeling more completely and to ascertain which prop wash results are more accurate, King County contracted with an independent third party consultant (Joe Scott; Tetra Tech FW, Inc.; October 2003) to review the submitted documents and make conclusions regarding the prop wash modeling. The results of the independent review are included as Appendix B.

The review (Scott 2003) concluded that neither model provides results that can be linked to impacts with certainty. Specifically, the review concluded that the model used by Dr. Jay

(Maynord model) is not appropriate to simulate conditions at the Maury Island site, primarily because the model was established using a river towboat (fixed shaft, ducted propellers and rudders) in a river canal situation (shallow flat bottom, vertical sides). This review does not provide convincing or reliable evidence to overturn the conclusions in the applicant's model. However, the review also concluded that while the applicant's model (JETWASH, based on Verhey model) may be more appropriate for the Maury Island site, the results are not accurate enough (display too much scatter) to assess impacts with certainty.

3.1.2 Significance criteria

The potential for prop wash related impacts to sediment and eelgrass was identified in the FEIS. New information and project changes would be significant if it is demonstrated that the revised project will adversely affect resources of special significance such as eelgrass in the nearshore environment beyond that discussed in the FEIS, or cause exceedance of state water quality standards beyond the level of impacts discussed in the FEIS. Where uncertainty exists, potential impacts from prop wash would be considered significant if they raise the likelihood of unmitigated impacts to probable.

3.1.3 Finding

Based on the independent review (Scott 2003- see Appendix B) of the prop wash modeling efforts, the new information submitted by both the applicant (JETWASH model and field verification) and the public (Dr. Jay; Maynard model and associated critiques of JETWASH) do not lead to the conclusion that the proposed project would result in any new probable significant adverse environmental impacts, as compared to those identified in the FEIS. The FEIS identified potential impacts to the eelgrass patches closest to the tug operations. Based on the uncertainty of the modeling results, the potential to impact these eelgrass beds still exists. However, the applicant has proposed a barge approach and departure protocol to reduce potential prop wash impacts to eelgrass, and an eelgrass monitoring program to identify elevated currents or damage to eelgrass due to prop wash. If elevated currents occur and cause potential damage, operations will be modified or halted to resolve the concern in consultation with the resource agencies. Therefore, although some uncertainty regarding the potential for eelgrass impacts remains, the proposal is less likely to cause these impacts than the proposal evaluated in the FEIS due to the extended dock and operations plan, and a mechanism to identify and correct impacts has been proposed.

3.2 Water Quality, Turbidity and Sediment

3.2.1 New information v. FEIS

The FEIS concluded that the project has the potential to cause turbidity impacts through the potential for sand and gravel spills along the conveyor and at the barge during loading operations and related to tug propeller wash suspension of sediments on the bottom. Mitigation for these potential impacts was proposed to include a barge approach and departure protocol, a cable haul-back system to maneuver barges at the dock, and a barge approach and departure plan (PIE 2002a).

New information on the issue of turbidity includes the new dock design, the new prop wash models (See Section 3.1 above), and a revised barge approach and departure plan. The new dock design locates barges further offshore and includes a conveyor enclosure that would eliminate spillage from along the conveyor. Extending the dock would also put any turbidity associated with spillage from the barges farther away from eelgrass beds where it is supposed to have the greatest effect on habitat value. Extending the dock would also reduce the potential for prop wash to stir up sediment from the seabed and reduce the impact of sediment disturbance on eelgrass, since the tugs would be operating in deeper water farther from sensitive habitat. As was stated in the FEIS, propeller wash has the potential to suspend fine sediment from the bottom.

Velocity monitoring at the eelgrass beds would be a part of the mitigation and monitoring schedule, and adjustments to barge maneuvering procedures would be made as necessary to prevent velocities of >75 cm/second at the eelgrass beds (Northwest Aggregates 2003).

3.2.2 Significance criteria

For the purpose of this analysis new significant impacts on water quality would be in evidence if conditions under the proposal increased the potential for exceedances of state marine water quality standards beyond that stated in the FEIS. The Washington State marine water quality standard for turbidity (the only water quality parameter identified as potentially affected by the project) is:

> …turbidity must not exceed: 5 NTU over background when the background is 50 NTU or less; or a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

This standard would be fully protective of eelgrass as well as other species that would be more sensitive to temporarily high turbidity.

A measurable alteration in bathymetry that results in a loss of area at an adequate depth suitable for eelgrass, would constitute a significant adverse impact not identified in the FEIS.

3.2.3 Finding

Two different propeller wash models were prepared and critiqued by an independent reviewer. The results of that review indicate that the true near bottom velocity and its effect on bed scour and turbidity have not been conclusively determined. Where there is an elevation of near-bottom velocity, there is the potential for fine sediment mobilization, which could cause a temporary increase in turbidity or alteration of bathymetry. The potential for this effect was stated in the FEIS.

The revised mitigation and monitoring plan allows for adjustments in barge docking and departure procedures, and possibly mitigation, should velocities of > 75 cm/second result from barge operations. Therefore the net effect of the new dock design, approach and departure protocol, and monitoring and mitigation approach do not indicate an increased probability of propeller wash related turbidity from the possibility that was acknowledged in the FEIS. While turbidity elevations during barge maneuvering may occur, the probable intensity of these impacts is reduced from the proposed action evaluated in the FEIS.

Turbidity effects from dock construction would also be reduced from what was proposed in the FEIS, since fewer pilings would be installed. The new dock design would completely contain the gravel conveyor, eliminating the potential for spills and wind blown material from the conveyor that could contribute to turbidity in the nearshore. Therefore, no new significant impact to turbidity from dock construction is anticipated. New information presented since the publication of the FEIS expands on the potential for propeller wash to cause turbidity impacts, but does not lead to a conclusion that there will be a new significant adverse impact from turbidity or to water quality in general.

3.3 Eelgrass and the Nearshore Marine Environment

3.3.1 New information v. FEIS

Since publication of the FEIS, new information regarding eelgrass and potential impacts to eelgrass in the project area has been submitted. These include:

- An updated eelgrass survey (PIE 2001).
- An analysis of the potential for shading impacts (PIE 2002b).
- Comments on plan for Glacier Northwest to reconstruct gravel barge dock and to mine sand and gravel on Maury Island (Phillips 2003 – *Report for Preserve our Islands*).
- Redesigned plans for the barge loading dock (See Section 2).
- An updated mitigation plan (Northwest Aggregates 2003).
- New analysis of the potential effects of propeller wash (See Section 3.1).
- A barge approach and departure protocol (Glacier Northwest 2003)

The updated eelgrass survey (PIE 2001) gives the most detailed inventory of eelgrass at the project site that has been done. Eelgrass distribution data presented in this report includes slightly different locations for individual eelgrass plants and a more detailed delineation and description of eelgrass density for the two larger eelgrass beds within the project area than was available in the FEIS. The general size, location, and eelgrass density are similar to what was reported in the FEIS with one important difference, a small patch on the north side of the dock observed by Jones & Stokes (1999) and MRC (1999) was no longer present. The 2001 survey

(PIE 2001) provides a baseline of eelgrass distribution and density that can be used for comparison with post project monitoring data to determine if impacts to eelgrass have occurred.

A shading analysis was completed (PIE 2002b) that evaluates the potential shading impacts of barge loading activity at the existing dock location, using the dock design in the FEIS. The shade analysis includes in-situ measurements of photosynthetically available radiation (PAR) at different depths and times of year. From these measurements it was determined that light would be limiting to eelgrass at a depth of 12 to 16 feet (MLLW=0) at this site. This is consistent with the eelgrass distribution currently found at the site, but somewhat less than what was assumed as the maximum suitable depth of eelgrass in the FEIS (22 feet [MLLW=0]). The shade analysis uses several conservative assumptions. For example the shade analysis does not take into account refraction and diffusion, which would reduce the shading affects described. The conclusion of the shade model was that barges at the dock would shade an area of seafloor of a suitable depth to support eelgrass, at certain times of the year. This shaded area would include some areas of existing eelgrass.

Without an alteration of the dock design or barge loading schedule, it would be possible that shade could reduce eelgrass coverage, if ameliorating factors such as refraction, diffusion, and actual times of barge loading are not taken into account. Since this analysis was completed, the dock was re-designed as described in Section 2. The dock redesign would reduce barge-related shade from existing and potential eelgrass sites, and would reduce the shade under the existing dock as well. However, shading along the trestle alignment would increase due to the longer gallery tube. Overall shading from combined facilities would be reduced.

Ronald Phillips, a recognized expert in eelgrass ecology and restoration, submitted comments on the plan for Glacier Northwest to reconstruct the barge dock and resume gravel and sand mining at the Maury Island mine to Preserve Our Islands (Phillips 2003). Dr. Phillips provides a synopsis of the many important ecological functions of eelgrass, including a discussion of the value of patchy eelgrass habitat. An important point in this report is that the areas of patchy eelgrass growth are areas with expansion potential and suggested that they should be protected as well as larger contiguous beds. Dr. Phillips also comments on mitigation sequencing, pointing out that under the accepted mitigation sequence, the project should first avoid impacts, and only minimize and mitigate if avoidance is not possible.

The new design for the barge loading dock includes features that would avoid shade impacts to eelgrass from barge loading, and reduce shade from the dock. By extending the dock further seaward, the new design would avoid barge shading the elevations suitable for eelgrass growth (<-16 feet MLLW), including the existing patches of eelgrass currently growing at the site. In addition, the use of metal grating in place of wooden decking would also reduce shade from the dock. In addition to avoiding shade, the dock extension also would reduce the potential effects of propeller wash on eelgrass at the site by moving the tugs to a distance greater than 100 feet from eelgrass patches. An additional feature of the new dock design is that the entire conveyor would be enclosed, thereby avoiding the impact of fugitive dust and sand deposition in the nearshore area. The loading chute would be a tubular structure that would further reduce fugitive dust during barge loading.

Following the new dock design, Glacier Northwest revised the mitigation plan (Glacier Northwest 2003). Because the revised mitigation plan includes the extended dock to avoid impacts, eelgrass replacement was included. Instead, the new mitigation plan includes a detailed monitoring plan to determine if any changes in bathymetry, eelgrass density, or eelgrass distribution occur in the four-year period following project implementation. The plan outlines an adaptive management procedure to negotiate corrective measures to rectify and/or reduce impacts, should the project monitoring demonstrate any impact to eelgrass, bathymetry, or temperature. Eelgrass surveys would be conducted in the summer of 2003 and before and after construction along depth contours and at established survey grids delineating the established eelgrass beds at the north and south ends of the project area. At 1, 6, and 12 months after construction the grid surveys would be repeated. Qualitative dive surveys would be completed at 2 weeks and 3 months following construction. Bathymetric surveys would be completed before construction and repeated annually to determine if project operation has resulted in a change in bathymetry. This would address spills of sand and gravel in the loading area.

Temperature monitoring is prescribed in the monitoring plan. Although there is nothing in the proposal that appears to have the potential to measurably affect temperature, this data could be useful if a change in temperature (from other causes) results in a change in eelgrass distribution or density.

Considerable attention has been given to the uncertainty of the potential effects of propeller wash from tugs on the nearshore marine environment, in particular the potential effect on eelgrass (See Section3.1). What can be said with certainty, is that there is a potential for tugs operating in the area to cause increased bottom current velocity within the area suitable for eelgrass growth shoreward of the barge loading area.

If increased velocity is high enough it can cause suspension of fine sediments, and under the right conditions, could erode bottom sediments. If the sediments within or at the edge of eelgrass beds are eroded, some loss of eelgrass could occur. Furthermore, an increase in sediment suspension would cause a temporary increase in turbidity, which, if it lasted long enough, could have an adverse impact on eelgrass and other species in the nearshore environment. This potential was discussed in the FEIS, and addressed in the mitigation and monitoring plan that called for eelgrass enhancement to mitigate impacts, should they occur. The mitigation and monitoring plan (PIE 2002a) also included (as does the revised plan) monitoring to determine the extent or lack of damage to eelgrass habitat. Under the revised mitigation and monitoring plan (Northwest Aggregates 2003), the process to identify and address impacts is the same as under the old plan. The one difference is that compensatory eelgrass mitigation was a planned activity under the old plan and is now something that would occur only if damage occurs and the type and extent of mitigation would be dependant upon negotiation with the permitting agencies. Under neither plan is the success of mitigation a known quantity.

3.3.2 Significance criteria

Eelgrass is considered the most ecologically valuable habitat along the project nearshore area, and the most vulnerable to project impacts. New project features or new information that would indicate an increased likelihood of a net loss of eelgrass habitat from what was assumed in the FEIS would constitute a significant impact.

3.3.3 Finding

Since the publication of the project FEIS, the distribution and density of eelgrass at the site have been described in greater detail. The potential impacts of the project to eelgrass have also been better defined. As a result, the dock has been redesigned. The new design includes features that avoid or reduce potential impacts. New information on propeller wash indicate that velocities sufficient to increase turbidity or cause bed scour, and possibly damage eelgrass are still possible, as was disclosed in the FEIS at the old dock location. The applicant has proposed an approach and departure protocol, which is designed to further minimize the potential for impacts from propeller scour. So, while the potential for impacts to eelgrass has not been eliminated, it has been reduced from what was reported in the FEIS.

Eelgrass and bathymetry monitoring would be conducted on a fairly rigorous schedule. The mitigation and monitoring plan (Northwest Aggregates 2003) includes a contingency planning and response section that "…identifies the steps that will be taken if the measures to avoid, minimize, rectify, and reduce…fail to mitigate unforeseen impacts from barge-loading operations. Additional contingency actions might include but are not limited to transplanting eelgrass, or restoring riparian areas at the site." The contingency planning process allows for the permitting agencies to have final approval of contingency mitigation response, should an impact be identified. Therefore, the revised mitigation plan prepared after issuance of the FEIS includes a procedure for addressing potential impacts to eelgrass, and no new probable significant impact to eelgrass.

3.4 Noise

3.4.1 New information v. FEIS

Since publication of the FEIS one new information letter was received by the County: a report dated November 26, 2002 from Bruck, Richards, Chaudiere, Inc. (BRC Acoustics). The report included the following: 1) a description of an alternative noise impact criterion (EPA Region X 1980 noise program guidelines for EISs) that would be more restrictive than those used in the DEIS and the FEIS; 2) detailed data showing that baseline noise levels taken by BRC in the summer of 1999 are quieter than the wintertime baseline levels described in the DEIS and FEIS; 3) Evidence that noise generated by active tugs might be louder than the assumed tug noise levels used in the DEIS and FEIS; 4) a qualitative discussion of why temperature inversions could exacerbate noise levels at homes with line-of-sight view of the new dock; 5) a qualitative evaluation of the unusual and unexpected noise modeling results presented in the FEIS for the various project phases; and 6) a qualitative discussion speculating that updated noise modeling to include louder tug operations and temperature inversions might indicated more frequent and widespread violations of the King County noise ordinance limits than were shown in the DEIS and FEIS.

It is important to note that all of the comments included in the November, 2002 BRC report were previously made by various commenters to the DEIS. The County's responses to comments included in the FEIS qualitatively addressed the each of the comments.

3.4.2 Significance criteria

The noise impact criterion used in the DEIS and FEIS was compliance with the King County noise ordinance limits. The applicant used a predictive noise model to assess future noise levels, and concluded that the nighttime noise limits could be exceeded at only one house near the facility boundary. Based on that modeled violation the applicant proposed post-startup noise monitoring and construction of noise barrier walls if the noise monitoring revealed an actual violation. Under the SEPA guidelines, a new significant noise impact would occur if either of two conditions were to apply: 1) a new, more restrictive, regulatory noise limit was imposed following publication of the FEIS which was exceeded or could not be met; or 2) new technical information became available indicating the modeled noise levels would increase enough to cause more frequent or widespread violations of the noise limits.

3.4.3 Finding

The November, 2002 BRC report did not include any new information indicating likely new significant noise impacts. Each of the major items in the report had already been revealed in various comments to the DEIS, and the FEIS included a response to each comment. The issue of whether to use the EPA Region X noise guidelines as an impact criterion was decided prior to the DEIS, and the County elected to rely solely on the County noise ordinance limits. BRC's 1999 baseline noise levels were alluded to in the DEIS comments and addressed in the County's FEIS responses. The summer 1999 baseline noise levels measured by BRC do not affect the FEIS's conclusion that modeled noise levels are lower than the County noise ordinance limit. The FEIS responses concluded that the noise sources and meteorological conditions included in the DEIS noise modeling were adequately protective. Therefore, no new information was revealed in the BRC report, and no significant new noise impacts would likely be modeled if BRC's requested changes to the modeling assumptions were implemented.

4 CONCLUSIONS

Our conclusions are based on the primary SEPA criteria under WAC 197-11-600(3)(b), which provides the standard to meet for significance sufficient to require a Supplemental EIS (see Section 1.3.1). Our conclusion in this regard is that there is no new probable significant adverse impact based on the factors we evaluated.

We conclude that the Maynord prop wash model offered by Dr. Jay as an alternative to the applicant’s model is not appropriate at this site and is of sufficient limitation in terms of accuracy, applicability, and certainty, that it cannot be used to disprove and replace the applicant’s model.

We conclude that the applicant's model, although more appropriate for this site, also has limitations and uncertainty not expressed by the applicant, and that it's potential effects on local eelgrass cannot be confirmed by this model, leaving potential impacts to eelgrass possible and somewhat uncertain.

We conclude that extending the dock, reducing the size of the dock, and increasing the light permeability of the dock reduces the adverse impacts to eelgrass identified in the FEIS. Removing all of the creosote pilings and replacing them with far fewer steel or concrete pilings reduces other impacts.

We conclude that the new ambient noise data provided since the FEIS actually reduces predicted impacts to residents, not increases them, and that the EPA noise significance guidance is not a basis of significance or enforcement at King County. This is the same position that was taken in the FEIS.

We conclude that potential impacts to eelgrass, and turbidity from prop wash, are uncertain due to the uncertainty surrounding the model outputs, and that the models neither dispel or confirm that prop wash impacts are possible with the new dock, but are less than if the dock had been built at its existing location. We also conclude that a combination of the new smaller dock, with grated deck, and greater distance from eelgrass, combined with uncertainty about the modeling results and the applicant's revised operations plan, do not create a new probable significant adverse impact as a result of project changes or new information.

We conclude that the applicant's original plan with proposed eelgrass replacement to occur at some time, which has been replaced with a new plan with an agreement to work with agencies to mitigate any impacts should they still occur, are nearly equivalent, and do not create a new probable significant adverse impact.

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Appendix A

SEPA Significance Threshold

SEPA Threshold Criteria – Significance

Although this effort is to decide on the need for a SEIS, rather than the need for an EIS, the significance criteria listed in SEPA are the same in either case.

SEPA defines a proposal needing an EIS as one which "is likely to have a probable significant adverse impact" (WAC 197-11-330 (1)(b)). SEPA provides various factors to consider in developing whether or not an impact (or impacts) is significant. These factors may be found at various locations in SEPA. This section combines them. They are defined in part in -330(3) (a-e). We apply these criteria to the factors studies in this report.

> "WAC 197-11…-330(3) In determining an impact's significance (197-11-794), the responsible official shall take into account the following, that:
>
> (a) The same proposal may have a significant adverse impact in one location but not in another location;
>
> (b) The absolute quantitative effects of a proposal are also important, and may result in a significant adverse impact regardless of the nature of the existing environment;
>
> (c) Several marginal impacts, when considered together, may result in a significant adverse impact;
>
> (d) For some proposals, it may be impossible to forecast the environmental impacts with precision, often because some variables cannot be predicted or values cannot be quantified.
>
> (e) A proposal may to a significant degree:
>
> (i) Adversely affect environmentally sensitive or special areas, such as loss or destruction of historic, scientific, and cultural resources, parks, prime farmlands, wetlands, wild and scenic rivers, or wilderness;
>
> (ii) Adversely affect endangered or threatened species or their habitat;
>
> (iii) Conflict with local, state, or federal laws or requirements for the protection of the environment; and
>
> (iv) Establish a precedent for future actions with significant effects, involves unique and unknown risks to the environment, or may affect public health or safety".

Note that many of these significance criteria are not the result of a single significant environmental impact. In addition to a proposal's direct and obviously significant adverse impacts, a proposal may be classified as significant and subject to a SEPA EIS:

a. because of it's location

b. as a result of a number of small impacts

c. uncertainty

d. effects on special resources

(i-ii) conflicts with existing laws

(iv) establishing a precedent

Having determined whether or not there is significance under these criteria, the next step is to determine whether a SEIS is needed under -600(3)(b). This decision must consider the impact whether it is new, whether it is significant, and whether it is probable. SEPA requires the Responsible Official to consider the context of the impacts, location, number of impacts and lack of information, as potential triggers requiring an EIS. The Responsible Official may use one or a combination of more than one of these criteria to make the decision. Our interpretation of the SEPA significance criteria, as the basis for the conclusions we make in this report, is discussed below.

WAC 197-11 330 -

(a) Given Project May Be Significant in One Location and Not Another. This evaluation factor considers the impacts of a project based on the location at which it occurs. It recognizes the sensitivity of a site, of adjacent lands, and those in the area. A project located in a highly populated area or environmentally sensitive area may have different concerns than the same project in environmentally sensitive, less populated, or less developed areas. For example, certain projects, e.g. waste transfer stations in industrial areas may be insignificant compared to potentially significant impacts of the same project in a residential neighborhood.

(b) Absolute Impacts Are Important, Regardless of the Existing Environment. We interpret this criterion to mean that significant impacts can occur even if the existing environment is or is not particularly sensitive to them (e.g., it is degraded, non-productive, barren, etc.). Here we look at the absolute impacts of the project, compared to its description in the June 2000 FEIS, to see if there is significance, regardless of site and location. This tells the Responsible Official not to discount impacts because the site maybe non-sensitive.

For all intents and purposes, we conclude that this significance factor can be ignored in making (will not have a bearing on) the Significance Decision. We see no evidence that the existing characteristics of the site are used to minimize the importance of any impacts. Although the site is designated as an industrial use for a mine, for example, significance criteria are applied to noise at the residential boundary using the state and County noise regulations. No environmental criteria or threshold has been reduced due to the existing environment at this site. This criteria was not applied to the analysis.

(c) Several Marginal Impacts When Added Together May Be Significant. We have evaluated a narrow range of specific new project changes and potential impact areas for this analysis. The County may wish to add their analyses to this list to determine whether the significance threshold is changed when considering new impacts when added to the County's noise impact analysis. They include:

- Water quality
- Eelgrass loss
- Noise
- Land use
- Regulatory compliance

This section describes the elements of the environment reviewed in this report, and concludes whether or not adding these impacts would be likely to cause a new significant adverse impact. In doing this analysis, we considered cumulative impacts as a factor in making a decision. However, because the County has yet to include their land use analysis, we have not attempted to apply the incomplete list of issues we examined to a significance determination under this category.

(d) For Some Proposals, it May Be Impossible to Forecast the Environmental Impacts with Precision, Often Because Some Variables Cannot Be Predicted or Values Cannot Be Quantified. This factor uses uncertainty as a potential reason to support a conclusion of significance. Aside from the fact that there is always some uncertainty in predicting the future, new information creating uncertainty for this project has been identified. For example, we have concluded that there is a level of uncertainty within the output of the applicant's model sufficient to be uncertain about potential impacts. Under SEPA, this would trigger significance and a need to issue an EIS if the uncertainty created a probable new significant adverse environmental impact.

(e)(i) Adversely Affect Environmentally Sensitive or Special Areas. This criteria is applicable to the importance or uniqueness of the eelgrass beds and other habitat at the site, and possibly to any shoreline designation or habitat designation for which limits have been placed on land use, development, activities within the shoreline zone, etc. We look at the habitat and its sensitivity to determine whether this site is particularly more vulnerable than other sites in Puget Sound. The FEIS discussed impacts to the Maury Island shoreline and this report evaluates impacts from the revised project and compares the differences. The County is looking at land use considerations.

(e)(ii) Adversely Affect Endangered or Threatened Species or Their Habitat. Endangered Species Act (ESA) compliance has been addressed in a Biological Assessment (BA) submitted by the applicant to the US Army Corps of Engineers (Corps). The BA concluded that the project may affect, but is not likely to adversely affect (NLAA) listed species. The Corps has submitted the BA to the Services (NOAA Fisheries and US Fish and Wildlife Service) for their concurrence as required by Section 7 of ESA. We reviewed the current proposal and submitted data to determine whether T&E species are affected more significantly now than when the FEIS was filed. We anticipate the County will consider the conclusion of the Services in this regard and may make a significance determination based largely on their decision as to whether this project is likely to affect T&E species.

(e)(iii) Conflict with Local, State, or Federal Laws or Requirements for the Protection of the Environment. The basis for this analysis is whether or not there are any new conflicts with laws or requirements that were not discussed or known earlier. The pending DNR shoreline designation may be a factor here, but only after the guidance criteria under the Aquatic Reserve are adopted. This is a Land Use topic for King County to assess. This document did address noise regulations.

(e)(iv) Establish a Precedent for Future Actions with Significant Effects, Involves Unique and Unknown Risks to the Environment, or May Affect Public Health and Safety.

Precedent for Future Actions with Significant Effects – We have not evaluated the likelihood of more expanded gravel mine operations in Puget Sound based on the creation of this proposal. It appears that most of the marine impacts are mitigatable. Upland impacts, except for noise that does not have a new significant adverse impact, are not within the scope of this review. We can find no precedent that this action would create. Thus, this criteria does not trigger the need for a SEIS.

Unique and Unknown Risks to the Environment – This guideline suggests that a proposal may be so different or its impacts so unique that its impacts would be unique or unknown. We also look at this to consider whether this proposal, at this location, would create impacts that would not likely occur elsewhere. None of the project changes or new information create unique or unknown risks to the environment that were not considered in the FEIS.

Affects on Public Health and Safety – No new information has been presented related to public health and safety (see noise addressed separately). This guideline is not a factor in deciding significance or the need for a SEIS and is not considered here.

Appendix B
Technical Memorandum

TETRA TECH FW, INC.

Memorandum

Date: 17 November 2003

To: Grant Bailey, Jones & Stokes
Greg Borba, King County DDES

From: Joe Scott

RE: Maury Island Gravel Project
Review of Propeller Wash Modeling

Introduction

The purpose of this memorandum is to determine, based on conflicting opinions of the same model predictions for propeller wash effects on Maury Island, which model output conclusions appear to be the most accurate. If it is not possible to make such a conclusion, a secondary purpose of the analysis is to provide a critique of the modeling efforts and to identify errors, incorrect assumptions, or uncertainties inherent in the modeling or in the conclusions based on the modeling. Jones & Stokes will then use this memorandum as part of their SEPA Threshold Analysis to assist the County in their Threshold Determination for this project.

Specifically, the following tasks are addressed:

1. Review the documentation provided.
2. Review the JETWASH model, addressing such issues as assumptions, accuracy and uncertainty, and conclusions.
3. Review the Maynord model and the Hill memorandum, also addressing the assumptions, accuracy and uncertainty, and conclusions.

4. Review the field investigation used to verify the JETWASH model, addressing whether uncertainties have been removed and conclusions strengthened.

5. Review the applicant's operation plan, commenting on whether the plan will avoid impacts to sediment and eelgrass, by avoiding excessive propeller wash, and suggesting any steps that could be taken to ensure successful implementation of the plan.

6. Deliver the above reviews in a memorandum to Jones & Stokes.

7. Attend a meeting with Jones & Stokes and a meeting with King County, delivering the memorandum and discussing the finding in the memorandum and providing explanations as necessary.

Except for the last task, the memorandum is organized in order of the tasks above.

Review

Jones & Stokes provided the following documents for review in assessing the propeller wash modeling at Maury Island:

1. Chapter 6, entitled *Marine Habitat and Fisheries*, of the Final EIS (June 2000) by King County describing impacts and mitigation for marine plants and animals at the Maury Island Gravel Dock, including impacts from propeller wash;
2. A Technical Memorandum entitled *Maury Island Dock Facility Propeller Wash Modeling* (September 5, 2002) by Pacific International Engineering describing the propeller wash modeling analysis used in support of the applicant's dock alternatives;
3. A Report entitled *An Analysis of Propwash, Spillage and Sediment Transport Impacts of the Maury Island, Glacier Northwest Gravel Mine* (2 December 2002) by Dr. David Jay presenting an alternative propeller wash modeling analysis and a critique of the modeling effort by Pacific International Engineering;
4. A Draft Mitigation Plan entitled *Maury Island Barge-Loading Opertaions (Extended Dock)* (May 5, 2003) by Northwest Aggregates proposing guidelines for dock operations to mitigate impacts;
5. A Technical Memorandum entitled *Propeller Wash Calculation for Northwest Aggregates Facility at Maury Island* (May 9, 2003) by Coast & Harbor Engineering describing the basis of the JETWASH model and its calibration procedures;
6. A Report entitled *Prop Wash and Sediment Resuspension at the Maury Island Glacier Northwest Gravel Mine* (June 19, 2003) by Dr. David Hill peer reviewing both the Pacific International Engineering (Document 2) and Dr. Jay (Document 3) modeling reports;
7. A Technical Memorandum entitled *Propeller Wash Measurements and Model Comparison - Maury Island Barge-Loading Dock* (August 14, 2003) by Coast & Harbor Engineering describing field measurements to calibrate their modeling analysis and critiquing Dr. Jay's (Document 3) modeling analysis;

8. A *Barge Approach and Departure Protocol* (August 14, 2003) by Northwest Aggregates describing a tugboat operations plan and presenting a propeller wash monitoring plan;
9. A Report entitled *Review of: Technical Memorandum Propeller Wash Measurements and Model Comparison - Maury Island Barge Loading Dock by PI Engineering and: Barge Approach and Departure Protocol by Glacier Northwest Both Dated 14 August 2003* (22 September 2003) by Dr. David Jay critiquing the Coast & Harbor Engineering Technical Memorandum (Document 7) and the Northwest Aggregates Protocol (Document 8);
10. A Technical Memorandum entitled *Re: Barge Approach and Departure Protocol, Northwest Aggregates – Maury Island Barge-Loading Dock* (September 29, 2003) by Northwest Aggregates responding to comments made in Documents 2 and 9 above regarding the propeller wash modeling and the barge operation protocols;
11. A Technical Memorandum entitled *Response to Review of Technical Memorandum Propeller Wash Measurements and Model Comparisons (David A. Jay)* (October 1, 2003) by Coast & Harbor Engineering responding to comments made in Document 9 above regarding the JETWASH model and its calibration.

The documents above describe the propeller wash phenomenon and the environmental conditions upon which the propeller wash is purported to act. An overview of both issues will help clarify the review comments that follow.

The propeller wash can be envisioned as a horizontal truncated cone (an old-fashioned megaphone provides a reasonable analogy) of jetting water coming from, and created by, the propeller. The small end of the truncated cone represents the propeller; the large-end and the sides of the truncated cone represent the limits of the jet where the jet velocities die out and fade into the surrounding water. The spinning propeller forces the accelerating water out as an expanding cone. Within the first 3 to 10 propeller diameter lengths (the actual length depending on a variety of propeller and water conditions) of the jet, the water is turbulent and fluctuates wildly with small swirls within the larger propeller-induced swirling. This confused zone is referred to as the "zone of flow establishment" and is well explained in Documents 3 and 7. This zone is important in discussing the potential for sediment scour near the gravel pier, but the eelgrass patches are beyond this zone. Beyond the zone of flow establishment is the "zone of established flow", also well explained in Documents 3 and 7. The water velocity in this expanding portion of the jet cone is less confused and the jet is more diffuse. This means that the jet cone spreads out laterally and the velocities in the jet decrease laterally and with distance from the propeller until they match the ambient water velocities at the edge and end of the cone. Theoretically, the maximum velocity occurs along the axis of the cone behind the propeller, but experimentation has shown that the presence of the propeller hub and a rudder can deflect the maximum velocity in the jet radially or toward the surface or seabed, whichever is closer to the jet axis. The models used in the above documents attempt to simulate the size of the cone, estimate the velocity distribution within the cone, calculate what the jet velocities are where the cone intersects the seafloor (water-sediment interface), and especially estimate the water-sediment interface velocities at the edge of the eelgrass patches.

The propeller wash jet (cone) is constrained in the real world at the Maury Island gravel dock by the surface of the water and the seabed. Therefore, knowledge of the configuration of the seafloor and thickness of the water column are important. The seabed at the Maury Island gravel dock slopes up from the depths of Puget Sound at a slope of about 1 vertical to 5 horizontal to the shoreline at a depth of 0 feet (MLLW). The eelgrass patches are at a depth of about –10 feet (MLLW). The intertidal seabed, between 0 feet and +20 feet (MLLW), flattens to about 1 vertical to 7 horizontal. The thickness of the water column varies with the tides. The mean tide range, based on the tide measurements at Tacoma, is approximately 8 feet, the diurnal range is about 11 feet, and the extreme range is approximately 18 feet. The combination of bottom slope and water level dictates where and how the propeller-jet will interact with the seabed. To provide acceptable results, the models need to simulate the propeller wash interaction with the seabed. In other words, the models have to be able to predict the jet velocities at the intersection of the jet cone with the seabed (water-sediment interface) for a range of geographical locations and environmental events simulating worst-case conditions.

The Applicant's Propeller Wash Model

The following are the review comments on the JETWASH model, addressing the assumptions, accuracy and uncertainty, and conclusions. The JETWASH model and the results of the model simulations are presented in three documents above (Documents 2, 5, and 7). For review of the JETWASH model, all three documents are treated together.

According to Documents 2, 5, and 7 above, the JETWASH model used the velocity equations presented by Verhey (1983) to calculate the velocity jet. The Verhey (1983) equations (see Appendix A) for the propeller wash jet were derived from theoretical considerations, with laboratory experiments on scale models used to calibrate the theoretically derived equations. The scale modeling provided empirically (experimentally) derived coefficients for equation calibration. Basically, the coefficients mathematically constrain the size and shape of the jet and smooth out the velocity fluctuations due to turbulence. Experiments were carried out at the Delft Hydraulics Laboratory in a basin of unspecified dimensions to determine the velocities in a propeller jet. Equations were provided for a free jet (unbounded) from either a stationary vessel or a maneuvering vessel. To make the equations more universal (capable of being used for a wide variety of vessels), the models included an ocean-going ship with open propellers, a conventional in-land motor vessel (European style), a high-powered vessel with ducted propellers, and a push-tow with twin screws. The ship models varied in scale from 1:25 (for the in-land motor vessel, the high-powered vessel, and the push-tow) to 1:82.5 (for the ocean-going ship). Scale effects were discussed, but were assumed to be negligible. Verhey reports that there was scatter in the test data, but he used an average value for the two empirical coefficients in his equations.

The JETWASH model by the applicant was used to simulate the "worst-case" near-bottom propeller wash velocity with 100 feet between the propeller and the offshore edge of the eelgrass patches adjacent to the Maury Island dock. The simulation was based on the tugboat *Westrac*, owned and operated by Western Towboat Company. The characteristics for the *Westrac* are given in Table 1.

The tugboat characteristics were used in the model equations and this resulted in an exponentially decreasing bottom velocity behind the propeller as shown on Figures 3 and 4 of Document 2 and Figure 25 of Document 7. The estimated near-bottom velocity was 1.3 ft/sec (40 cm/s) at both the north and south eelgrass beds with the propeller 100 feet seaward of the beds (the distance from the eelgrass beds to the face of the extended dock). This velocity is presented to occur at 26 cm (10 inches) above the bottom. Document 7 reports that the equation coefficients were recalibrated after a field test (see below for a discussion of the field test) using the tug *Westrac*. The recalibrated coefficients were the same as those reported by Verhey (1983). The results of the simulations were presented in tabular and graphical form. The conclusions from the modeling (Figure 25, Document 7) were that the estimated near-bottom velocities 100 feet aft of a stationary *Westrac* would be about 85 cm/sec (2.8 ft/sec) and it would take at least 33 seconds for the velocity field to develop. There were no details as to how the velocity field development time was calculated.

There were inherent assumptions made in using the JETWASH model. The model assumes that velocities calculated for a free jet are the same for a jet intersecting the surface and seabed. Stated another way, the jet intersection with the water surface or seabed does not disturb or distort the jet and the velocities calculated within its boundaries. This assumption is not supported by current available literature. In fact, one would expect some modification of the velocity field near the boundary, especially the seabed. The exact nature of the water-sediment interaction at the seabed is not known precisely. The jet is compressed where it intersects the seabed, thus the water velocity in the jet is expected to increase; however, the friction between the water jet and the sediment is anticipated to increase, thereby slowing the water at the interface. It is not know which phenomenon dominates. The JETWASH model and the Verhey equations do not directly account for this interaction. Verhey (1983) portrays a logarithmic decrease of velocities in the jet away from the central maximum velocity. This logarithmic decay of velocity is assumed to continue to the water-sediment interface. Coast & Harbor Engineering (Document 5) used the velocity measured (and calculated) 26 cm (0.26 m or 0.85 feet) above the seabed. This corresponds to the elevation of the lowest current meter used in their field tests for calibration. If the assumption of a logarithmic decay of the velocity is correct, the reported/calculated interface jet velocities should be conservative (i.e., slightly higher than expected in nature).

The two empirical coefficients used in the model to calculate the maximum centerline velocity are based on an average from scattered data per Verhey (1983). In Document 2, it appears that the velocities in the propeller wash jet were calculated using coefficients different than those recommended by Verhey (1983). Varying the two coefficients (called b and c by Verhey) from the published values can change the results appreciably. Jay (Figure 2, Document 10) illustrates the logarithmic effect that varying coefficient b has on the calculated maximum velocity/initial velocity ratio. Coefficient c is inversely proportional to the maximum velocity/initial velocity ratio. This means that decreasing coefficient c by a particular percent increases the ratio by a comparable percent and, conversely, increasing the coefficient by a particular percent decreases the ratio by a comparable percent. Documents 5 and 7 report the results of field tests used to recalibrate the coefficients used in Document 2. The calibration involved a comparison of calculated and measured velocities behind the tug based on adjusted coefficients. The field test results supported the same coefficient values as those reported by Verhey (1983), thereby bringing the JETWASH model more inline with the literature.

The JETWASH modeling provides a single velocity at each of the eelgrass patches. There was scatter in the measured data versus the calculated data (Figures 21, 23, 24, and Appendix E in Document 7). Therefore, it is concluded that there is sufficient scatter in all the contributing data that the calculated velocities have scatter. It would have been more appropriate to report a range of velocities at the eelgrass patches or provide an estimate of the statistical spread of the velocities.

The Maynord Model

The following are review comments on the Maynord (2000) model and the Dr. Jay and Dr. Hill reports, which concluded that there would be impacts on eelgrass or sediment. Comments address such issues as assumptions, accuracy and uncertainty, and conclusions.

Maynord (2000) investigated the physical forces near and under commercial tows in a river and canal waterway system (the Upper Mississippi River-Illinois Waterway System to be specific). A 170-foot long, 40-foot wide, by 9-foot draft towboat with 9-foot diameter propellers (actually a scaled 1:25 push-boat model) was tested in a 410-foot long, 70-foot wide, by 4-foot deep rectangular tank at the U.S. Army Waterways Experiment Station. The tests were conducted to confirm earlier equations by others, including Verhey (1983), using the towboat (push-boat) under stationary and maneuvering conditions. The testing provided an equation for the near-bottom velocity from propeller wash using only one empirical (experimentally derived from the tests) coefficient.

In Document 3 above, the Maynord (2000) model was used to calculate the maximum bottom velocity at the edge of the eelgrass patches. Document 3 used the vessel characteristics of the *Westrac* from Document 2 as input into the Maynord equation. For the new (extended) pier configuration, bottom velocities of about 1.25 m/s (4.1 ft/sec) at the south eelgrass bed and bottom velocities of 1.1 m/s (3.6 ft/sec) to 1.9 m/s (6.2 ft/sec) at the north eelgrass bed were obtained.

Whereas the Maynord model (really a set of equations, see Appendix A) better represents the interaction of the propeller wash jet with the bottom (seabed), the test setup to calibrate the equation uses a configuration and vessel very different than that to be found at the Maury Island gravel dock. The Maynord model used an inland towboat with different characteristics (see Table 1) than the tugboats to be used in towing gravel barges from Maury Island. Also, the model was calibrated in a specific section of the Mississippi River system with a flat seafloor, and not the sloping seabed found at Maury Island. The arguments in Document 3 to address the effects of slope on the model are unconvincing and outside the modeling effort used to develop the Maynord model. Therefore, the Maynord model is judged to be the wrong model to use for assessing the effect of propeller wash at the Maury Island gravel dock. Both Documents 3 and 6 state that the Maynord model is “state-of-the-art”. Unfortunately, what they fail to add is that it is state-of-the-art for a large towboat pushing a combination of several barges in a rectangular cross-section waterway of the Mississippi River System.

Dr. Hill (Document 6) is correct when he states that “Even within the subset of prop wash and sediment resuspension, it is difficult to give an accurate quantitative assessment of the impacts.” That is because it is beyond the ability of the simple equations used in the above reports to predict the characteristics of a very complex natural process. The comparison of the models and their results is a purely academic exercise. The equations were all derived from model vessels or model propellers in a laboratory. Scale effects of modeling are dismissed in the derivation of both models. Real world conditions at Maury Island are different from those laboratory conditions used to derive the equations used by both contributors.

Field Investigation

The field investigation used to verify the JETWASH model was reviewed, addressing whether uncertainties have been removed and conclusions strengthened.

The field investigation was reported in Document 7. Current meters were installed near the north eelgrass patch and a large tug, the *Westrac*, was maneuvered past and away from the current meters. The current meters recorded the velocities in the propeller wash jet 26 cm above the seabed as the tugboat sailed past.

Table 1. Comparison of Towboat and Tugboat Characteristics Used as a Basis for Propeller Wash Modeling.

	Maynord Model	**JETWASH Model**
Type	Towboat	Tugboat
Name	*MV Benyaurd*	*Westrac*
Length, feet	170.6	72
Beam (Width), feet	40.7	30
Draft (depth), feet	9.0	13
Total Engine Horsepower (HP)/RPM	4,300/NA	2,500/1,200
Propeller Axis Below Waterline, feet	4.5	10
Number of Propellers	2	2
Propeller Diameter, feet	9.0	6.3
Propeller System	Fixed Shaft, Open (Non-ducted) Propellers	4:1 Reduction Z-drive, Ducted Propellers
Maximum Propeller RPM	NA	300
Number of Rudders	6	None
Stationary Thrust (Estimated), pounds force per Propeller RPM	43,000/NA	15,000/175

A major concern with the field test is that the JETWASH model used the stationary form of the Verhey equations, but performed the testing in a maneuvering mode. This means that the propeller wash jet did not come to equilibrium and the coefficients based on the results of the field tests may be suspect, even though they are the same as those published by Verhey (1983). In other words, the field data for a maneuvering tugboat resulted in the same equation coefficients as those average values from a set of experiments on stationary model boats. This correspondence of field and experiment for the model coefficients may be real, coincidental, or an artifact of field data interpretation errors.

The propeller wash velocities from the field tests (Figures 2, 21, 23, and 24 in Document 7) show a large degree of scatter. For example, a modeled velocity of 60 cm/sec on Figure 23 shows comparable measured values from 20 cm/sec to 110 cm/sec. The scatter suggests that the velocities reported in Document 7 may be off the calculated average by as much as ± 50%. While it would have been more conservative to recalibrate the model coefficients so that all the calculated versus field measurement velocities lay on or above the line of perfect agreement, comparing the calculated-values to measured-values made 26 cm above the bottom provides conservatism in the opposite direction. This suggests that the coefficients used in the modeling are average coefficients (as reported by Verhey) and some scatter in the velocities is to be expected.

In conclusion, the field tests calibrate the JETWASH model to the average coefficient values reported in the literature, but real propeller wash velocities at the eelgrass patches can be expected to have some scatter around the reported values.

Operations Plan

The following is a review of the applicant's Operation Plan, with comments on whether the plan will avoid impacts to sediment and eelgrass, by avoiding excessive propeller wash, and suggestions that could be taken to ensure successful implementation of the plan.

The Operation Plan (Document 8) describes the typical operation options available to the operators of the Maury Island gravel dock, describes several tugboat configurations that may be used, suggests conditions to be placed on the tugboat operations, and provides a plan to monitor propeller wash at the eelgrass patches.

Impacts to the sediments and eelgrass patches will decrease with any combination of the following improvements:

1. increasing the distance between the tugboat propellers and the eelgrass,
2. increasing the propeller tip distance above the seabed,
3. decreasing the propeller rpm when operating near the eelgrass beds,
4. pointing the propellers away from the eelgrass patches.

By extending the face of the dock further offshore, the applicant is improving items 1 and 2. Item 2 is improved because the seabed depth increases with increasing distance offshore. By restricting tugboats to operating offshore of the breasting dolphins and staying on the offshore side of the barges improves items 1 and 2. By restricting the make-up configuration (Figures 3 and 4 in Document 8), item 4 is improved. No restrictions are placed on propeller rpm, but even if rpm restrictions were in place, it would be difficult to enforce and monitor them. It appears the applicant has made a reasonable attempt to improve operation and limit impacts to the seabed and eelgrass beds.

The following are some suggestions to improve the propeller wash monitoring plan:

1. Employ an independent third-party to install and operate the current meters.
2. Install the current meters as close to the seabed as practical.
3. Hard wire the current meter power source and recording to a station affixed to the dock or designated dolphin. This aids in system maintenance.
4. Devise a way to turn the current meter recordings on when a tug is within 1,000 feet of the dock and turn the recording off when it leaves the area; otherwise record continuously while the tug is present.
5. Record the current speed at least 2 times a second or as reasonable, but do it continuously; no averaging should be allowed.

6. Have a multi-disciplinary group review the current speed limitations that trigger further action.

Memorandum

This model review memorandum will not address every claim and counterclaim presented in Documents 3, 6, 7, 9, 10, and 11. Instead, the objective is to comment on the general strengths and weaknesses of each modeling effort, with an attempt to put the results in the real world context for conditions at the Maury Island Gravel Dock.

Both models yield a steady-state solution to a very dynamic, and in some cases random, process. Given a specific set of conditions (input), both models yield a single calculated velocity. Current meter records from actual field tests behind a propeller in the jet wash slipstream exhibit a widely varying velocity pattern in time and space. This means that the results of the models can only be approximations of a real propeller wash jet, and the definition of the velocity that the model is simulating has to be defined precisely. Typical definitions include the maximum peak velocity of all fluctuations, the maximum velocity of the steady-state portion of the jet, the average velocity of the steady-state portion of velocities in the jet, or some other user defined measure of the jet velocity fluctuations.

The models (sets of equations) used by both parties were developed under laboratory conditions sufficiently different from the real world conditions to be found at Maury Island that both sets of modeling results are considered approximations only. Actual current meter records taken in a propeller slipstream exhibit a fluctuating (jagged) record of speed versus time [see Figures 11 through 20 in Document 7, or Appendix A in Maynord (2000)]. Flow is very turbulent and velocities fluctuate wildly, sometimes over one order of magnitude. It is this kind of behavior that the models are trying to simulate/replicate.

The major differences between the models are that the Verhey model attempts to simulate a free propeller jet stream (unconstrained in all directions) for several classes vessels, and the Maynord model simulates a constrained (water surface and seabed) propeller jet for a towboat in a rectangular cross-section channel.

These models cannot provide accurate bottom velocities from propeller wash. Model results are only approximate. Since both of the models are based on scaled model tests in a laboratory, scale effects and turbulence may affect the development of the equations, the empirical coefficients thus derived, and the modeling results. Verhey (1983) alludes to scaling effects, but because he cannot measure the effects, assumes they are negligible. Verhey (1983, Page 4) and Maynord (2000, Page 6) both dismiss the random small-scale turbulent eddies in their model development and provide instead formulations based on the maximum average velocity distribution in the propeller wash jet.

The Maynord model results are probably inappropriate to use in this situation. The Maynord modeling was done using a river towboat (fixed shaft, ducted propellers and rudders) in a river or canal situation (shallow flat bottom, vertical sides). In fact, Maynord states that the model cross-section represents the Mississippi River at Clark's Ferry, river mile 468.2. The situation at Maury Island is different: a tugboat (rotating ducted propellers and no rudders) at the edge of a fjord-like shore (sloping bottom). While the qualitative statements made by Dr. Jay, and supplemented by Dr. Hill, provide a good description of the propeller wash phenomenon, the quantitative results from the Maynord modeling effort (and by implication, the resulting equations) do not replicate the conditions at Maury Island.

The Verhey modeling effort attempted to predict "approximately" (Verhey's wording) the velocities behind a propeller of a maneuvering ship. Several types of ship models were investigated. Empirical coefficients are used to "adjust" the equations to the vessel under discussion. Verhey alludes to the scatter in the data used to derive the coefficients. Using the field data to calibrate the model coefficients is reasonable so long as the velocity averaging time is less than the velocity averaging time used to set the threshold velocity for sediment erosion and eelgrass damage. The reported velocity from the Verhey-derived equations used by Coast & Harbor Engineering is an approximation of the average maximum velocity near the seabed.

In conclusion, the Maynord model used by Dr. Jay is not appropriate to simulate the conditions at the Maury Island dock. The Verhey model used by Coast & Harbor Engineering may be more appropriate for the Maury Island dock conditions, but the results do not adequately address the interaction of the propeller wash jet with the seabed and the results are not accurate enough (display too much scatter) to assess impacts precisely.

Qualitatively, from Verhey (1983) and Maynord (2000) we have learned that the propeller wash jet is cone-shaped. The velocities within the cone are quite turbulent right behind the propeller and become less so farther away. The maximum velocity within the cane may not necessarily lie along the propeller axis, especially if a rudder is present. The velocity within the cone decreases with increasing distance behind the propeller and, taking into consideration the previous statement, with increasing distance from the propeller axis. The propeller jet may be deflected to the surface or the seabed if the propeller is near (unspecified) either. The interaction of the propeller jet with the seabed is complex and confused, and the state-of-the-art to adequately address this issue is still being formulated by investigators at institutions around the world.

References

Maynord, Stephan T. *Physical Forces near Commercial Tows*. Interim Report For The Upper Mississippi River – Illinois Waterway System Navigation Study, ENV Report 19, U.S. Army Corps of Engineers Research and Development Center, Vicksburg, MS, March 2000.

Verhey, H.J. *The stability of bottom and banks subjected to the velocities in the propeller jet behind ships*. Delft Hydraulics Laboratory, Publication No. 303, April 1983.

Appendix A

Model Equations

Verhey (1983) Model

From Verhey (1983), the velocity distribution in the "zone of flow establishment" is given by:

$$V_{x,r}/V_o = \exp\{-[(r/D_o)+(cx/ D_o)-0.5]^2/2c^2(x/ D_o)^2\},$$

and, the velocity distribution in the "zone of established flow" is given by:

$$V_{x,r}/V_{max} = \exp[-(r/D_o)^2/2c^2(x/ D_o)^2];$$

where $V_{x,r}$ is the axial velocity (parallel to the propeller axis) in the propeller jet at an axial distance x behind the propeller and a radial distance r from the axial line of the propeller. The maximum centerline velocity in a propeller wash jet behind the propeller (V_{max}) can be estimated by:

$$V_{max}/V_o = (2cx/D_o)^{-b},$$

where D_o is the initial slipstream diameter or minimum diameter of the propeller wash behind the propeller, c is an empirically determine coefficient, b is an empirically determined coefficient, and x is the axial distance behind the propeller. Verhey reports average values for coefficients b and c of 1.0 and 0.18, respectively. He also notes that:

$$D_o = D_p \text{ for a ducted propeller,}$$

$$D_o = 0.71D_p \text{ for an open or non-ducted propeller;}$$

where D_p is the propeller diameter. V_o is the axial efflux velocity from the propeller or the mean velocity of the water immediately behind the propeller and is given by:

$$V_o = 1.6nD_p(K_{tp})^{1/2},$$

where n is the propeller rotational speed. K_{tp} is the thrust coefficient specific to the propeller and is given by:

$$K_{tp} = T/(\mathtt{r}n^2D_p^4).$$

Maynord (2000) Model

From Maynord (2000), the propeller velocity distribution for a stationary vessel in the "zone of flow establishment (Zone 1)" is given by:

$$V_{x,r} = V_{(xp)max}\exp(-r/2c^2x_p^2), \text{ with r measured radially from } C_J;$$

where $V_{x,r}$ is the velocity acting along propeller axis at r radial distance from location of $V_{(xp)max}$ and x_p from propeller, $V_{(xp)max}$ is the maximum propeller jet velocity as a function x_p for a single propeller in Zone 1 or multiple propellers in Zone 2, and c = 0.18. The vertical distance (C_J) from the center of the propeller to the location of $V_{(xp)max}$ is given by:

$$C_J = -|\{\tan(12°)[x_p-(S_{back}/2)]\}-\{C_{para}g[x_p-(S_{back}/2)]^2/[V_2^2\cos^2(12°)\}|;$$

where g is the acceleration of gravity, S_{back} is the hoprizontal distance from the propeller to the stern of the vessel, and $C_{para} = 0.12(D_p/H_p)^{2/3}$ for an open propeller, or = 0.04 for a ducted propeller. The maximum propeller jet velocity is given by:

$$V_{(xp)max}/V_2 = 1.45(x_p/\ D_p)^{-0.524}.$$

The velocity caused by the propeller is given by:

$$V_2 = (1.13/D_o)(T_p/r)^{1/2};$$

where T_p is the thrust per propeller, r is the density of water, and D_o is defined as above.

In the “zone of established flow (Zone 2)” the bottom velocity from a stationary vessel is given by:

$$V_{bot}/V_{surf} = 0.34(D_p/H_p)^{0.93}(x_p/D_p)^{0.24};$$

Where H_p is the vertical distance from the channel bottom/seabed to the center of the propeller, and the other parameters are as defined above. The surface velocity is given by:

$$V_{surf} = V_{(xp)max}\ \exp[-r^2/2c_{x2}^{\ 2}x_p^{\ 2}];$$

where $c_{x2} = 0.84(x_p/\ D_p)^{-0.62}$, and the maximum velocity is still geven as:

$$V_{(xp)max}/V_2 = 1.45(x_p/\ D_p)^{-0.524}.$$

The initial velocity from the propeller is given by:

$$V_2 = (1.13/D_o)(T_p/r)^{1/2};$$

where the thrust per propeller (T_p)is a function of the system thrust (T) given by:

$$T_p = T/N,$$

where N is the number of propellers.

Maynord also gives the propeller wash velocity for a moving vessel relative to the vessel as:

$$V_{prop,v} = E(D_p/H_p)V_2\{1\text{-}c_{func}\ \text{abs}[(V_a\text{-}V_g)/V_2](H_p/D_p)^{1.5}\},$$

where the empirical coefficient E = 0.43 for open propellers and 0.58 ducted propellers. The coefficient c_{func} = 0.25 for ducted propellers and 0.50 for open propellers. V_a is the average ambient (channel) velocity and V_g is the vessel speed relative to the ground.